Non-diffusive thermal conductivity in semiconductors at room temperature

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Phonon-mediated thermal transport on a microscale deviates from the predictions of the thermal diffusion model. We find that in single crystal materials such as Si and GaAs the Fourier law breaks down at distances much longer than previously thought, >1 micron at room temperature and above. We use the laser-induced transient thermal grating technique in which absorption of crossed laser pulses in a sample sets up a sinusoidal temperature profile monitored via diffraction of a probe laser beam. By changing the period of the thermal grating we vary the thermal transport distance within the range ~1-10 microns. In measurements performed on thin free-standing Si membranes and on bulk GaAs the thermal grating decay time deviates from the expected quadratic dependence on the grating period, thus providing model-independent evidence of non-diffusive transport. The simplicity of the experimental configuration permits analytical treatment of non-equilibrium phonon transport with the Boltzmann transport equation. Our analysis shows that at small grating periods the effective thermal conductivity is reduced due to diminishing contribution of "ballistic" low-frequency phonons with long mean free paths (MFPs). Our findings appear to be contrary to textbook numbers for phonon MFP, ~40 nm for Si and ~20 nm in GaAs at room temperature; however, the results are in agreement with recent first-principles calculations of thermal conductivity spectrum of Si that indicated a large contribution of low-frequency phonons with MFP >1 micron to the room temperature thermal conductivity.

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